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Lightning Protection
Review of Past LTRI Researches Relating to KC-135 and Similar Type Aircraft

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Lightning & Transients Research Institute
Minneapolis, Minnesota

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NOTICES

FOREWORD

This report was prepared by the Lightning and Transients Research Institute under Contract AF 33(616)-7828 sponsored jointly by the Aeronautical Systems Division, U.S. Air Force and the Navy Department, Bureau of Naval Weapons.

The technical program is administered under the direction of the Communications Laboratory, Aeronautical Systems Division, Mr. H.M. Bartman acting as project chief, and coordinated with the Bureau of Naval Weapons through Mr. V.V. Gunsolley.

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ABSTRACT

LTRI past investigations of lightning hazards and protection of multi-jet aircraft have been reviewed for application to the KC-135 and similar type aircraft. Flight experiences of commercial jet operations have been utilized in determining economics as well as possible hazards. Use of protection conductors for the nose radome is recommended as economic as well as effective in reducing a slight hazard. Lightning protection systems of some type, or at least of review of present systems, is recommended for all antennas leading into the fuselage. Current studies of possible streamer and lightning stroke hazards to fuel vents suggest the application of lightning diverter systems. No serious hazard is anticipated from most honeycomb construction. Consideration should be given to possible precipitation-static radio interference from lightning protection devices and in some cases they can be used to reduce this type of interference. Suggested for further study are the possibility of entry of DC lightning stroke components into the aircraft interior, lightning hazards from some types of fuel gage and fuel tank filler caps and electrostatic hazards from fuel tank liners.

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I. Introduction

A general review has been completed of past LTRI researches which relate to lightning protection of the KC-135 and similar type aircraft. The study has drawn upon the experience which Lightning & Transients has obtained in devising lightning protection for similar multi-engine jet transports and by review of the limited number of flight damage reports received to date on military and commercial multi-engine jet aircraft. A unique problem for the KC-135 is the large quantity of JP-4 fuel carried in the fuselage, a fuel which is flammable throughout the lightning ambient temperature range. The reduction of precipitation-static radio interference which has been encountered to date on the three American jet transport aircraft currently in use has also been considered.

II. Lightning Protection for the Nose Radome

Artificial lightning discharge model studies were made earlier on the three current commercial jet transports and a summary of the strike percentages to various parts of the aircraft for the three aircraft is presented in Table I. Insufficient flight damage reports have been received to date for good comparison with the above table but some severe strikes have been reported. As shown in Table I, a large percentage of strikes may be expected to the aircraft nose, which extends quite far ahead of the wing and therefore lightning damage to the radome may be anticipated.

A variety of lightning protection methods have been devised by Lightning & Transients for use on the various types of aircraft radomes in current use, and these include radomes for fire control radar, ECM antenna

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TABLE I

Probability of Lightning Strikes to Various Points as Determined from High Voltage Model Studies

Part Struck	Flight Damage Records Propeller Aircraft	Jet Transport A	Jet Transport B	Jet Transport C	Average
Rudder & Vertical Fin	9	16	16	16	16
Nose	12	33	37	24	31
Wing tip	21	21	19	19	20
Elevator & Horizontal Stabilizers	13	16	22	21.6	20
Jet Pod or Propeller	7	8	3	13.5	8
Tail Cone	4	4	3	2.7	3
Misc.	34			2.7	1

equipment, search radar and weather radar. The most direct protection method is a system of metal strips on the outside of the radome to conduct the discharge safely across the dome surface to the aircraft frame. These protection strips may be of various cross-sectional areas, depending upon a balance of tolerated damage probability in relation to the frequency of lightning strikes expected. For example, radomes on aircraft used for early warning service in which the aircraft may be required to remain in storm areas for extended periods require semi-permanent protection with conductors of large cross-sectional area up to 40,000 circular mils as illustrated in Figure 1. At the other extreme, aircraft such as the modern jet transports, which fly principally over the weather, may use thin foil strips for single shot protection as shown in Figure 2, as these are easy to apply and can probably be replaced between recurrent exposures to lightning. Other methods, which have been used, include conducting buttons grounded to the radar structure and exposed on the outside of the radome, lightning diverter rods, and special paints which guide the discharge over the radome surface, as shown in Figure 3. For the KC-135 a fairly substantial external conductor system is suggested, if one can be provided without excessive interference to the antenna operation. Also the use of conductive paint over the radome external surface is suggested, as it has been found that frictional electrification may puncture the radome surface to produce small pin-holes which, through subsequent rain erosion, may enlarge to produce extensive radome damage. Reports have been received in which failure of the radar dish to revolve was found to be caused by a large spongy cellular mass inside the radome caused by rain erosion and absorption on a radome which appeard from the outside to be intact.

To summarize, the use of a protection system is recommended for the radome on the basis that it is economic as well as safer to provide protection. The use of a conducting paint over the entire radome surface is also recommended for prevention of static puncture and subsequent rain erosion damage.

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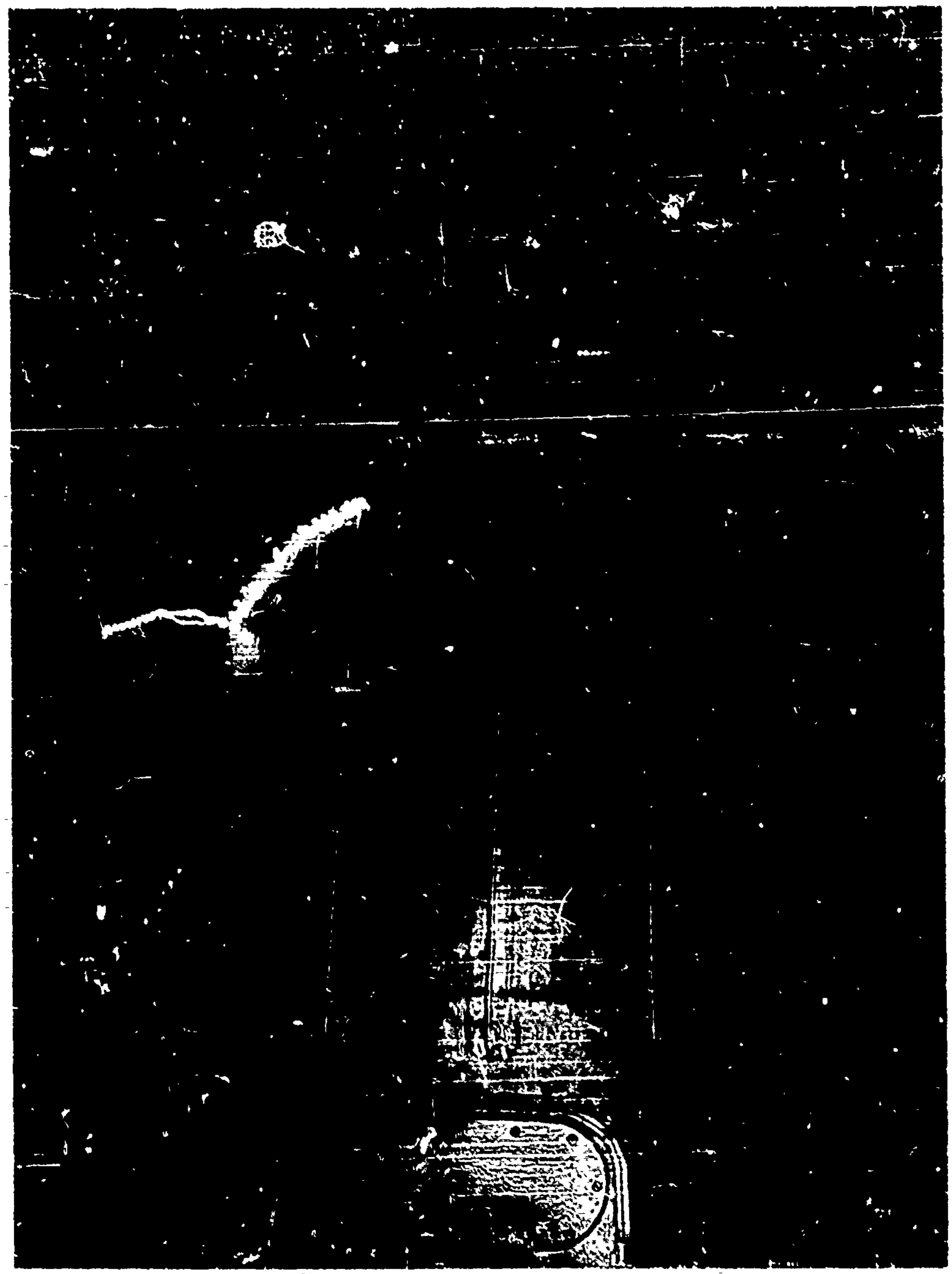

Figure 1. Two million volt artificial lightning discharge to radome protected by semi-permanent aluminum conductor.

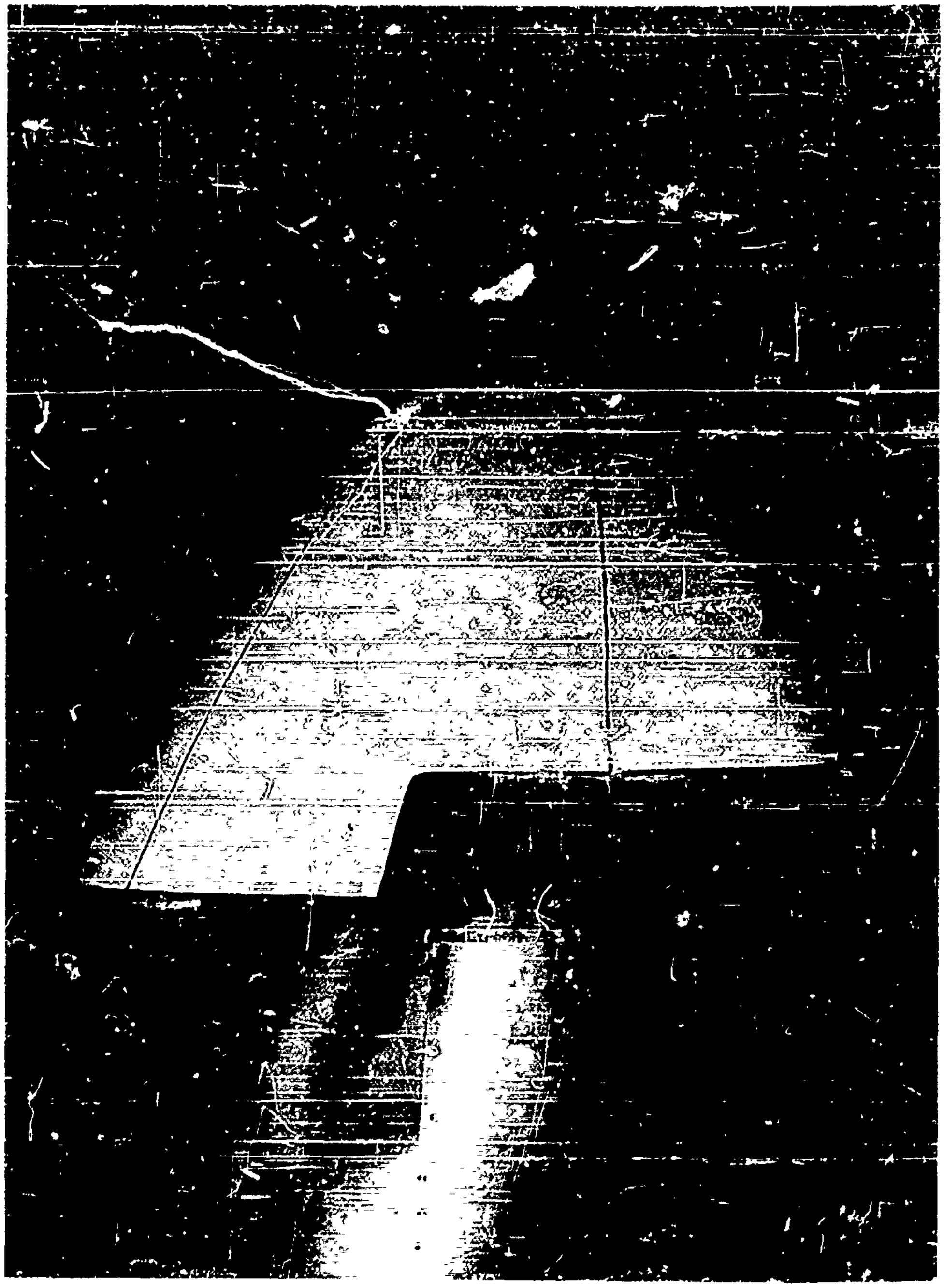

Figure 2. Discharge to radome protected by single shot foil protection system.

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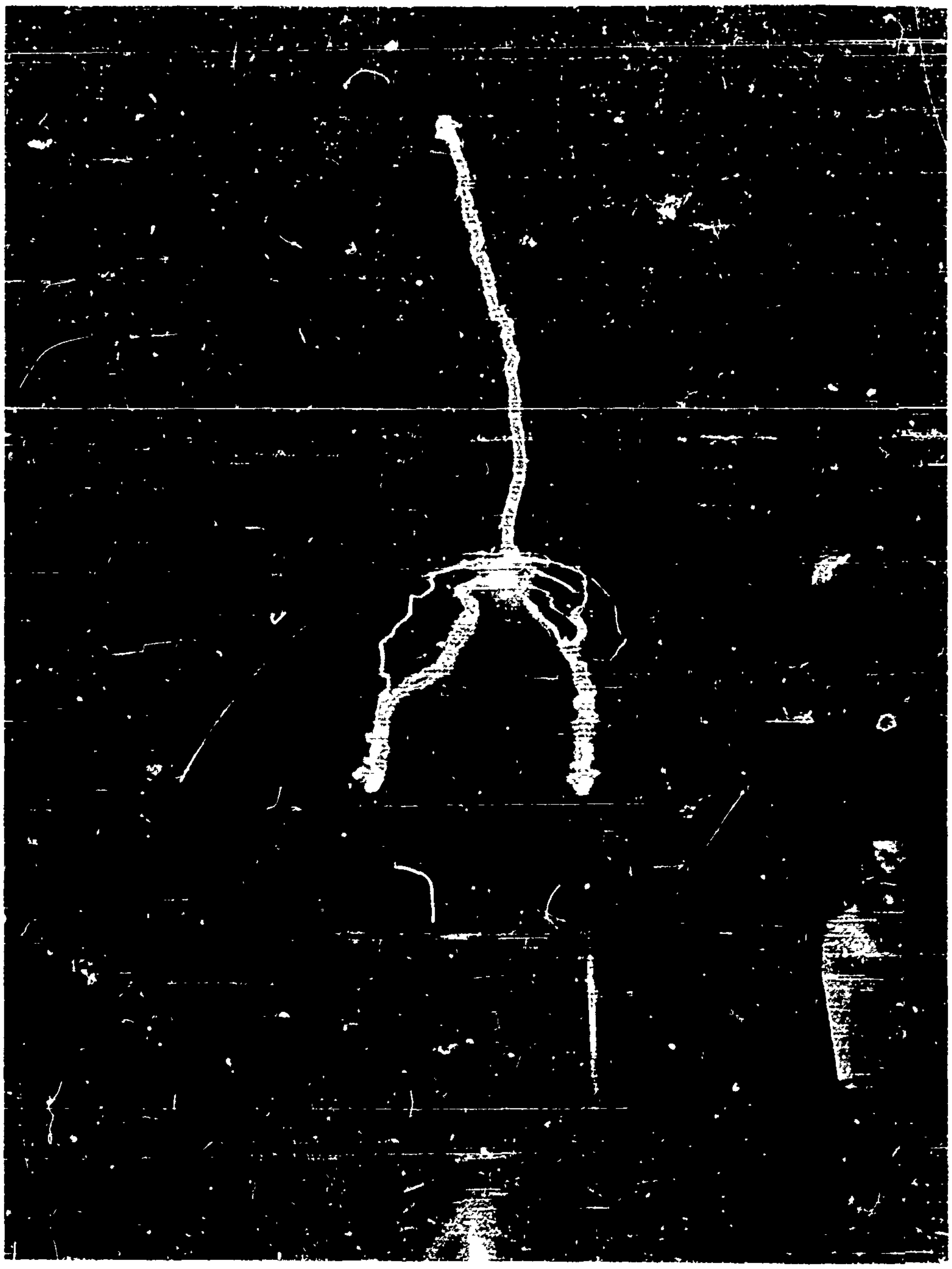

Figure 3. Discharge to special radome with aluminum paint used for lightning stroke diverting.

III. Antenna Lightning Protection

The Lightning and Transients laboratory had earlier devised a special aircraft lightning arrester, based on the concept that lightning discharges should not be allowed to enter the interior of the aircraft, for in addition to the direct damage to radio equipment which they may do, the ignition of fuel vapors may be possible. A capacitor spark gap lightning arrester was devised by LTRI and is now in general use for HF radio equipment protection. For isolated gap antennas with fiber lass structures, the lightning arresters perform an equally important function of containing an internal lightning stroke arc which could otherwise vaporize plastic resins to produce high gas pressures and explode the section.

The importance of lightning arresters such as used with the KC-135 probe antenna has been verified by a flight damage report received recently, and which is shown in the photographs of Figures 4 and 5, of a lightning discharge to a Boeing 707 aircraft probe antenna section. The lightning arrester had not been installed and accidentally no ground had been attached to the antenna. Thus the discharge to the probe passed to the air frame through the interior of the fin cap section by means of an air arc, and produced excessive gas pressures to blast out the inspection panels. In this case no serious structural damage was done. Had the section been more rigidly contained, the explosive damage might possibly have been more serious. This case, where no arrester was installed, and where the antenna was not grounded, illustrates the type of damage possible if an arrester were not used at all in the fin cap.

Strikes to the nose of the KC-135 should constitute a large percentage of the total strikes, as determined from model studies and these strikes will be swept along the fuselage by the action of the windstream. Consequently any type of antenna leading into the fuselage in line with the swept stroke, whether HF or VHF, may permit stroke entry into the

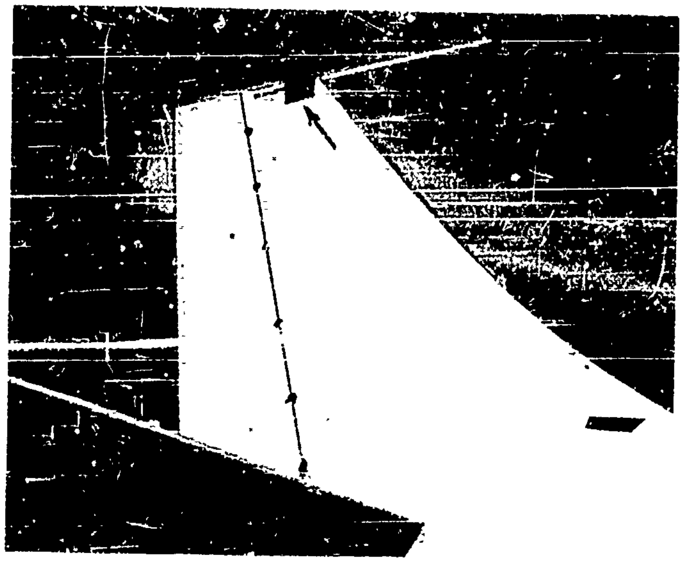

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Figure 4. Damage from natural lightning discharge to fin probe antenna, with blown out panel (at point of arrow) when lightning arrester was not installed and antenna not grounded.

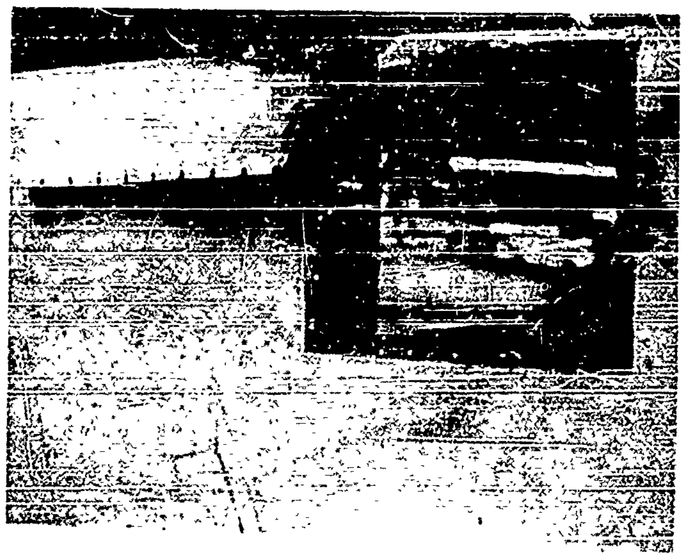

Figure 5. Close up view of blown out inspection panels from natural lightning discharge to the antenna shown in Figure 4.

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aircraft interior. For example, LTRI records of lightning damage to commercial aircraft indicate that as much damage is done to VHF radio equipment by lightning strikes as to HF, but no VHF protection has been used to date because of relatively lower past consideration as to importance. An illustration of the lightning damage to be expected on VHF antennas is shown in Figure 6. The damage was produced by a moderately severe laboratory discharge.

An alternative to the use of VHF or UHF lightning arresters is the development of lightning resistant VHF antennas. In many cases VHF-UHF antennas may be constructed with solid DC grounding, which effectively minimizes the amount of lightning stroke energy which may penetrate into the aircraft interior. The particular construction is important to assure that there is adequate current carrying capacity through the stroke current path, particularly at the connection to the aircraft fuselage

Early warning aircraft are subject to a relatively large amount of lightning damage, as they are sometimes required to remain in storm areas for extended periods of time, and they are struck by lightning discharges which penetrate the interior of the aircraft, generally through radio antennas. Thus, protection of some type is suggested for all antennas located on the fuselage.

IV. Fuel Vents in Relation to Potential Lightning Hazards

Earlier work on aircraft fuel vents considered the direct problem of the possibility of a lightning strike to a vent, which might ignite flammable fuel mixture in the vent. With the KC-135 carrying JP-4 fuel, which is flammable throughout the ambient lightning strike range, this problem becomes more important than with the kerosene fueled commercial transports. Tests of vents similar to the KC-135 have shown that

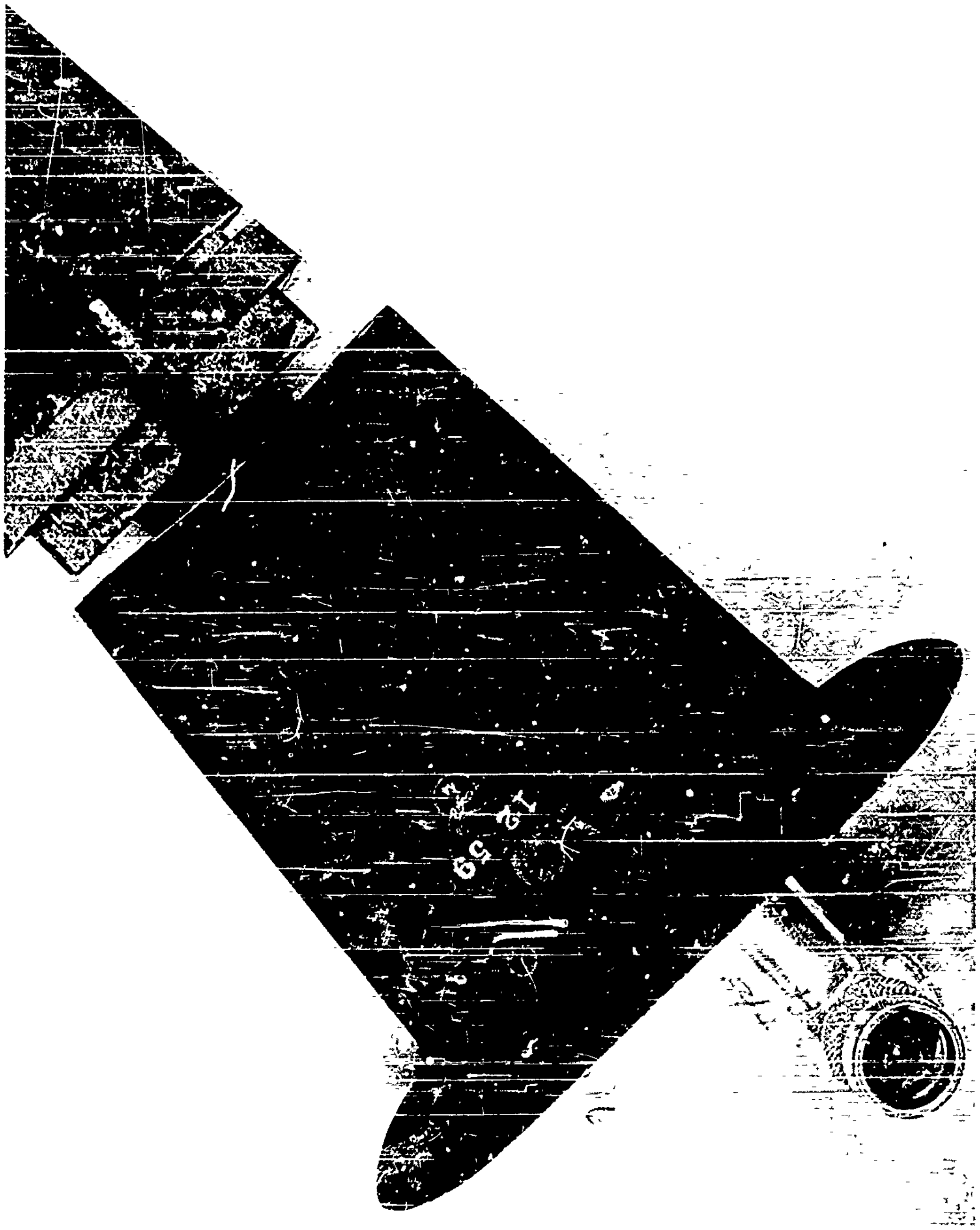

Figure 6. VHF antenna blown into three pieces by moderately severe artificial lightning discharge.

because of the vent's shielded location underneath the wing in a flat area, direct lightning strikes are not highly probable. LTRI records of lightning discharges to aircraft have shown very few discharges to wing tips further inboard than one foot. However, additional problems have been considered. These are: the possibility of inducing streamering on the vents with nearby lightning discharges which could produce ignition of the fuel vapors, or possibly the presence of continuous corona discharges due to friction electrification of the aircraft which might produce ignition of fuel vapors.

Investigations carried out earlier under Contract AF 33(616)-3991 and presented in L & T Report 363 have indicated that for most vent configurations, the possibility of corona ignition of fuel vapors produced by friction electrification is not likely; however, the probability of lightning induced streamers off nearly any vent configuration is very high and streamer ignition may be possible. As a lightning stroke contacts an aircraft, it immediately raises the aircraft potential to many millions of volts, which produces streamering off the entire aircraft, including most vents. Oscillograms of laboratory streamer current magnitudes presented in Figure 7 indicate currents exceeding 50 amperes for a fraction of a microsecond. This corresponds approximately to the time-current waveform required for ignition of fuel vapors under laboratory conditions as determined at our laboratory under an NASA program, NASA Tech. Note DN-440.

One additional possibility is the effect of lightning stroke pressure waves in propagating flame fronts through a vent or merely in passing through a vent to produce a detonation type of ignition of the flammable fuel vapors inside the tank. Therefore, although the present vent configuration has represented a reasonable configuration from the view of the previous state-of-the-art, some questions of streamer ignition and pressure wave effects near fuel vents remain to be answered.

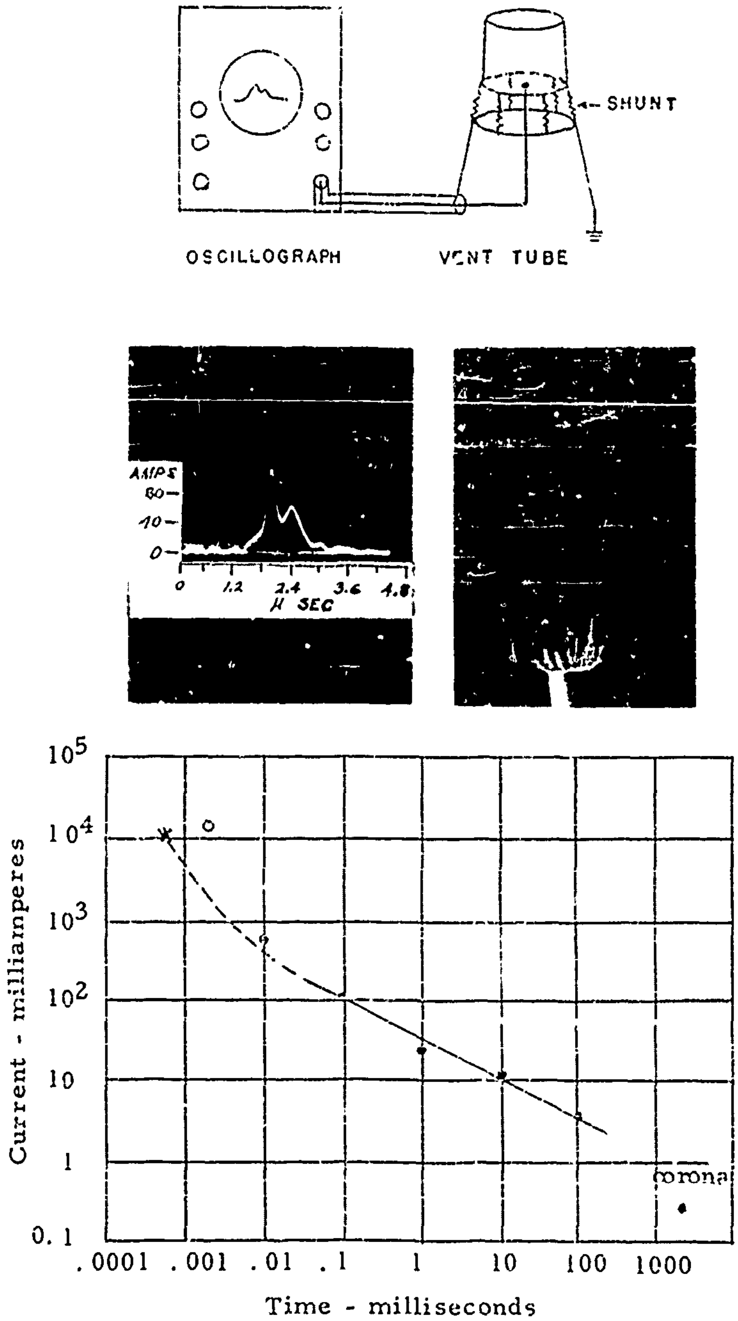

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Figure 7. Oscillogram of induced streamer current from vent tube produced by laboratory two million volt impulse, with current components comparable to top points of graph from NASA-LTRI study of explosive fuel flame propagation.

Where fuels are unavoidably carried quite near the aircraft wing tip, an arrangement which is definitely not recommended from a lightning point of view, the use of a plastic wing tip section with a metal diverter rib running the length of the wing tip is recommended to reduce the possibility of strikes inboard which could puncture fuel tank walls to cause ignition. The rib may be made of solid aluminum or may incorporate a resistive strip along the outside edge to reduce the corona discharge radio interference.

Because of the low pressure wingtip vortex, the edge of the wing tip is one of the first points on the aircraft to discharge corona currents under strong electric fields produces either by thunderstorm charge regions or by charge on the aircraft. These corona discharges can produce serious radio interference if they take place from metal or may quietly discharge the aircraft, if they take place from resistively decoupled dischargers. Therefore a combined metal and resistive plastic rib is recommended. This plastic wing tip with a diverter rib running longitudinally along the tip, has been adopted for smaller aircraft with less spacing between the fuel tanks and the wingtip, and would also be recommended for larger jet aircraft for discharging static currents as well as for lightning protection. A diagram of this system is shown in Figure 8. Protection may also be provided by lightning diverter rods in some cases, preferably the graded resistance type to minimize radio interference. Operation of a graded resistance diverter rod is shown in Figure 9.

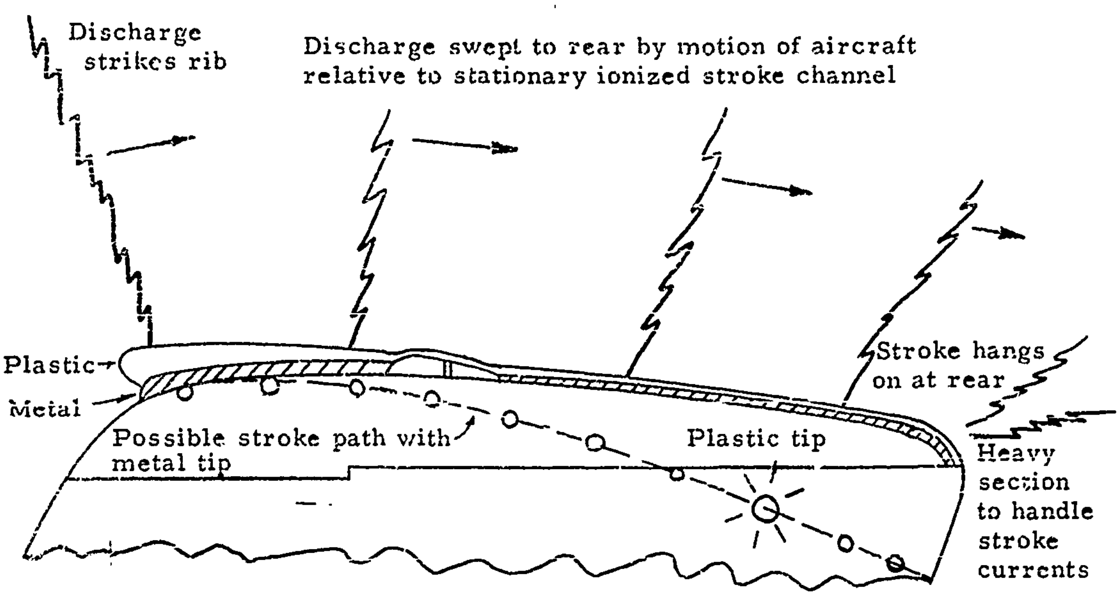

Figure 8. Diagram of the operation of wingtip diverter rib.

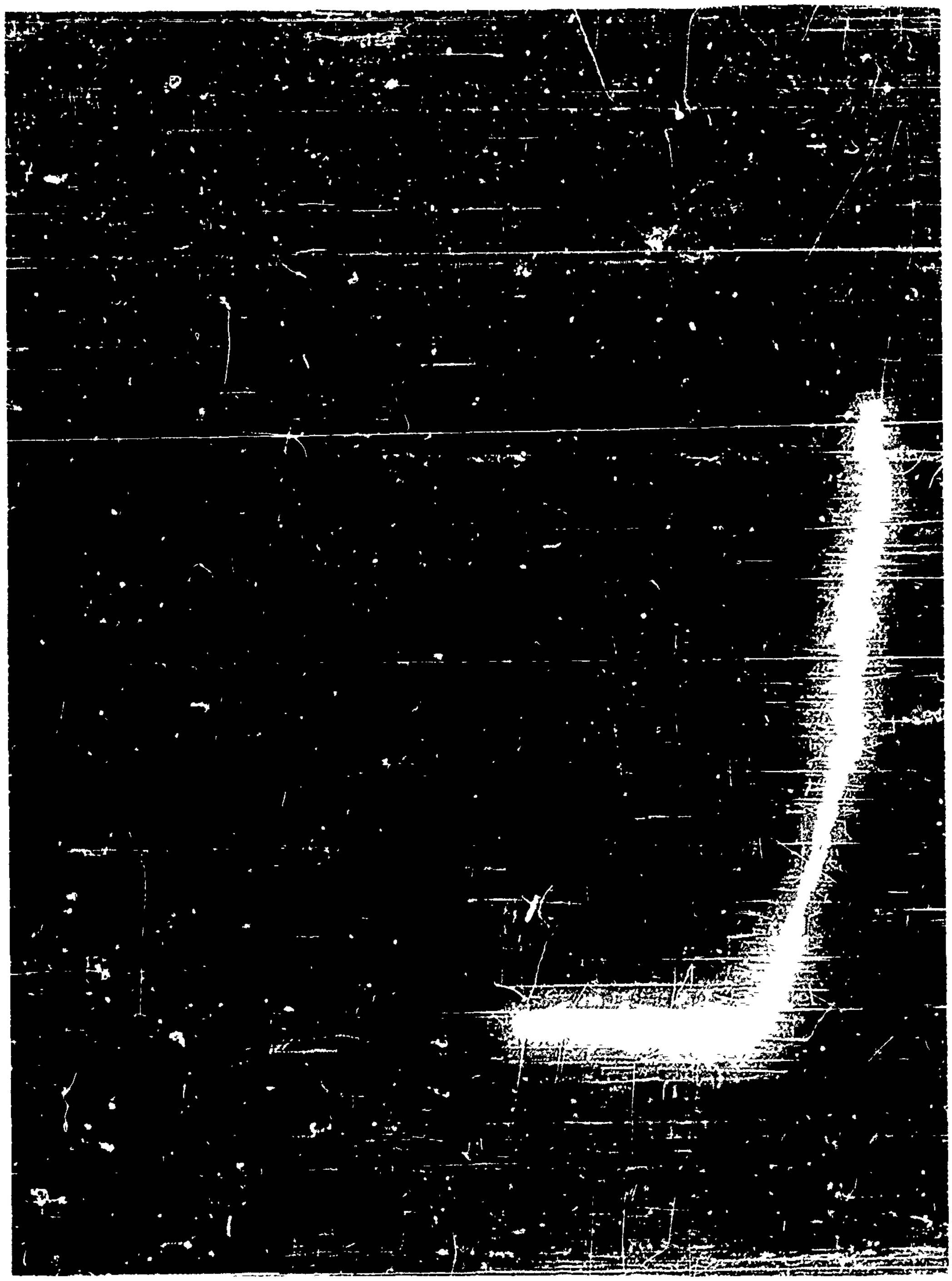

Figure 9. Operation of graded resistance lightning diverter rod on jet transport fin cap.

V. Honeycomb Materials

Investigations have been made for the three large American jet transport aircraft on possible lightning strike hazards to honeycomb materials which are used extensively for trailing edges, flaps, etc., and these investigations have disclosed that because of the nearly continuous metal paths in the honeycomb, very little damage is done by lightning discharges. The discharges tend to develop gas pressures by vaporization of the adhesives used at the external sheet metal joints; however, the extent of the damage is generally limited to a few square inches which might be expanded to possibly five or six inches under the influence of windstream. There remains one possible honeycomb type of configuration which could produce a serious hazard, and this is the foamed-in hinge joint. By imbedding the hinge base in a foam type plastic, long path lengths through the dielectric from the outer skin might be possible. It is this type of path through which lightning discharges can pass to vaporize the resins and produce very high gas pressures. Conceivably, a foamed-in type of honeycomb section hinge mounting could be blown entirely away from the hinge by a discharge to the surface. If this were a flap surface, for example, it could constitute a serious hazard to the aircraft. For most of the honeycomb sections checked to date at LTRI, the damage and energy produced by severe artificial lightning discharges has been small.

VI. Precipitation-Static Related to Lightning Protection

In general, lightning protection devices for aircraft are located at the aircraft extremities, points where lightning strikes are most probable, and therefore, consideration must be given to precipitation-static reduction, so the lightning protection devices shall also minimize radio interference. Such lightning protective devices include lightning diverter rods on the aircraft wingtips or empennage and protection strips on the aircraft radomes. Wherever possible, an effort should be made to

resistively decouple the actual corona discharge from the aircraft as it results in precipitation-static radio interference.

For example, LTRI has developed graded resistance lightning diverter-discharger rods. The primary function of these rods is to divert lightning discharges approaching the aircraft to specific locations which have sufficient conductor cross-sectional areas to safely carry the discharge in and out of the aircraft. Instead of being metallic the diverter-dischargers have graded resistance surfaces, which resistively decouple the corona discharges taking place in their extremities from the aircraft, so that in addition to preventing the diverter function from introducing interference, the diverter also quietly discharges the aircraft functioning as a combined diverter-discharger.

Another example of this technique is the reduction of precipitation-static which might result from lightning protection conductors an aircraft nose radome protective strips. To reduce the interference which might be produced on such strips, resistive coatings are strongly recommended for all radomes. The resistive coating acts to shield the metal strips to greatly decrease the electric field and corona threshhold on the strips.

When longitudinal metal lightning diverter strips are installed on aircraft wingtips to reduce the tendency for strokes to move inboard into possible fuel tank areas, again a resistive decoupling strip along the extremity of the lightning diverting strip is strongly recommended. On wingtips, the decoupling distance between the discharge and the metal strip is generally reduced to a few inches by aerodynamic requirements. However, even in these cases, a considerable reduction in the interference produced in the aircraft antennas is obtained by use of the resistive strips. Thus wherever lightning protection is installed, consideration must be given to the possibility of its producing precipitation-static radio interference and adequate interference reduction methods should be employed.

LTRI investigations of friction electrification on an aircraft has indicated that this is a lesser problem than lightning with relation to ignition of fuel vapors. However, one particular problem must be considered from point of view of both friction electrification and charge transfers due to lightning cross fields on the KC-135 and on refueling type aircraft in general. This is the possibility of a difference of potential between the refueling aircraft and the one being refueled, which could result in a static spark at the entrance to the fuel tank. This is an old problem which has been considered for many years in ground refueling trucks, and in view of the much larger capacities of aircraft, some type of static low-current drain system, preceding the actual contact of the fuel flow between the two aircraft is suggested.

VII. Remaining Problems which Suggest Additional Study

High current lightning discharges with high current rates of change, such as are common in cloud to ground discharges, have high frequency components, as considered from a Fourier spectrum standpoint, and therefore are carried by virtue of skin effect principally in the outer skin of the aircraft. As the overall resistance from one extremity to the other of the modern, all-metal aircraft is extremely low, the skin provides an effective shield to high frequency fields, and effects inside the aircraft are very small. However, with the longer duration, low current rate-of-rise strokes typical of many cloud to cloud discharges. the current paths are determined primarily by the DC resistance from one extremity to the other, and this permits the entry of large currents into the aircraft interior through low resistance paths, where they may produce sparks directly. Lightning discharges to aircraft have been known to knock out nearly all radio equipment, including HF, VHF, navigation equipment, and some electrical circuits by entry through aircraft antenna lead-ins. Because of the fuel carried in the KC-135 fuselage, the possible entry of DC lightning stroke components into the aircraft through low resistance interior paths needs to be considered.

One point of possible entry of lightning discharges into the aircraft is through the wing tip navigation lights, and this point has not been sufficiently developed to date. Strikes through the navigation lights could permit the entry of stroke currents into the aircraft interior wiring. The distance of penetration would be determined primarily by the circuit resistances, particularly with low rise discharges where inductive effects were minimized.

Another possible point of entry into the aircraft is through inspection covers for fuel gages or filler caps for fuel or oil tanks For example, it has been found that many aircraft are designed with O-ring fuel tank filler caps such that the primary high current paths from the filler cap to the air frame are inside the fuel tank. Therefore, a lightning discharge to an aircraft jet pod, for example, could be swept back over the wing surface to a fuel filler cap to produce contact resistance spark inside the fuel tank as illustrated in Figure 10.

On the KC-135, the fueling boom extends from the rear of the fuselage, where many lightning strike may be expected. Lightning strikes to this boom, although probably [illegible]d from fuel tank areas by valves and pumps, may produce sparking at t[illegible]ection points, which could produce fuel vapor ignition inside the fuselage. Thus, bonding of the fueling boom to the fuselage structure should be checked. The use of graded resistance diverter rods at the trailing end of the boom to attract and carry the lightning discharges would be desirable but could interfere with the boom operation and would require careful tests for proper installation with respect to both lightning and fueling operation.

Another point to be checked, though not pertaining to lightning, is that of electrostatic hazards inside fuel tanks. Recent investigations of high speed fueling have shown that extensive electrification is produced, but that there is little tendency for ignition. The recent development of

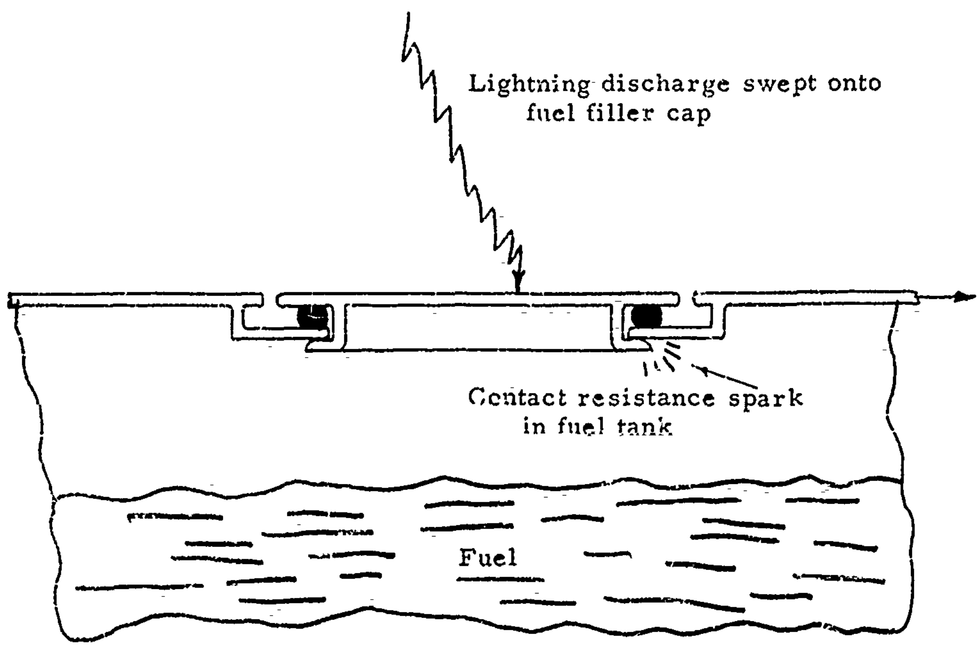

Figure 10. Sketch of fuel tank filler cap on which lightning discharge produces arc inside tank.

high dielectric strength paints such as the epoxies has introduced a possible electrostatic hazard. The advantages of this material for corrosion inhibiting have led to its use in flammable areas. The high resistivity dielectric strength can produce and store energies which may be 1000 times as great as those produced by fueling electrification, as the latter can involve only the spaces or liquid surface capacities which are minor compared to the capacities of a thin dielectric film paint surface. The stored energies produce large electrical discharges in the 10's of joules range corresponding to the ignition energy of an aircraft spark plug. The use of the high dielectric strength surface coatings for the interior of the fuel tanks in the KC-135 should be checked to assure that they are not introducing an unnecessary hazard in themselves.

VIII. Concluding Discussion

The specific lightning protection and interference reduction program proposed for the KC-135 type aircraft include tests of the weathering and ruggedness of the graded resistance lightning diverter rod and the wing tip protection rib and evaluation of various type dischargers. The graded resistance lightning diverter-discharger rods have been checked in the laboratory to determine their effectiveness in diverting lightning discharges but their resistance to flight environment, weathering and rain erosion remains to be determined. A flight test program on a KC-135 aircraft is proposed.

Considerable research work remains necessary on advancing the "state-of-the-art" knowledge on aircraft fuel system hazards from lightning in general, as had been proposed by LTRI for NASA and Industry support. In the interim a program is considered worthwhile for completing development of VHF lightning arresters and for the investigation of the other specific points of possible hazard on the KC-135 such as wing lights, fuel tank covers and refueling booms.

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